Development Board EPC9511 Rev. 1.0 Quick Start Guide

EPC2107

10 W Multi-Mode Wireless Power Amplifier Board

EPC
EFFICIENT POWER CONVERSION

DESCRIPTION

The EPC9511 is a high efficiency, power demonstration amplifier capable of operating to multiple wireless power standards. It can operate to the Qi standard of the Wireless Power Consortium (WPC), the Power Matters Alliance (PMA) standard (now merged with AirFuel™ Alliance) and AirFuel (formerly A4WP) wireless power standards. In AirFuel resonant mode, hence referred to as AirFuel mode, the EPC9511 system operates at 6.78 MHz with the amplifier circuit configured for ZVS operation. In this mode, the system can deliver up to 10 W of power into the source coil. In Qi/PMA inductive mode, the system operates at 165 kHz with the amplifier circuit configured for hard-switching operation and can deliver up to 5 W of load power into the device. An external oscillator can be used to operate the board to any desired frequency. The purpose of the EPC9511 is to simplify the evaluation process of both resonant and inductive wireless power technologies using eGaN® FETs and eGaN® ICs.

The amplifier board features various enhancement-mode GaN devices which are:

• The 100 V rated EPC2107 half-bridge eGaN® IC with integrated synchronous bootstrap FET used in the main wireless power amplifier.

• The 100 V rated EPC2036 eGaN FET used in the ZVS disconnect switch circuit and the main device of the SEPIC converter pre-regulator.

• The 100 V rated EPC2038 eGaN FET used in the controller circuit for changing set points based on operating mode.

The amplifier is configured for single ended operation and includes the gate driver(s), oscillators, and feedback controller for the pre-regulator, which ensures operation for wireless power control based on the AirFuel standard. This configuration allows for testing compliant to the AirFuel Class 2 standard over a load range as high as ±35j Ω. The pre-regulator features the 100 V rated 65 mΩ EPC2036 as the main switching device for a SEPIC converter.

The amplifier is equipped with a pre-regulator controller that adjusts the voltage supplied to the class D amplifier based on the limits of three parameters: coil current magnitude, DC power delivered to the amplifier, and maximum amplifier supply voltage. The controller ensures that all the three parameters operate within their respective limits. Changes in the device load power demand, physical placement of the device on the source coil and other factors such as metal objects in proximity to the source coil all contribute to variations in coil current, DC power, and amplifier voltage requirements. Based on load conditions, the controller will ensure the correct operating conditions for the class D amplifier based on the AirFuel standard. Operation in the Qi/PMA mode follows the same procedure where only the voltage, power, and current levels are adjusted accordingly. While this does not fully follow the Qi standard, it allows the EPC9511 to demonstrate the capabilities of eGaN FETs and ICs in a multi-mode system. Enhanced micro-controller based control systems can allow the system to operate and be compliant to either standard.

The pre-regulator can be bypassed to allow testing with custom control hardware. The board further allows easy access to critical measurement
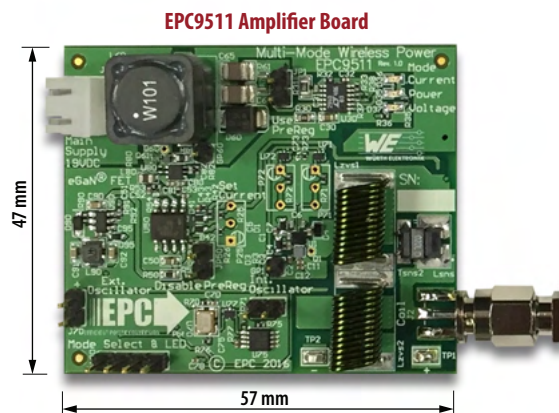
EPC9511 Amplifier Board

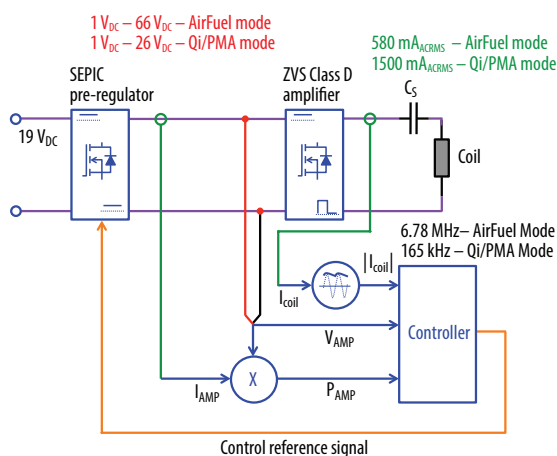Figure 1: EPC9511 wireless power amplifier board

Figure 2: Block diagram of EPC9511 multi-mode capable wireless power amplifier controller.

nodes facilitating accurate power measurement instrumentation hookup. A simplified control diagram of the amplifier board is given in figure 2.

For more information on the EPC2107, EPC2036, and EC2038 eGaN FETs please refer to the respective datasheet available from EPC at www.epc-co.com. The datasheet should be read in conjunction with this quick start guide.

DETAILED DESCRIPTION

The Amplifier Board (EPC9511)

Figure 2 shows the control system block diagram of the EPC9511 ZVS class D amplifier with pre-regulator and figure 3 shows the power schematic. The pre-regulator is used to control the ZVS class D wireless power amplifier based on three feedback parameters:

1. The magnitude of the coil current indicated by the green LED,

2. The DC power drawn by the amplifier indicated by the yellow LED and,

3. A maximum supply voltage to the amplifier indicated by the red LED.

Table 1: Performance Summary ($T_A = 25°C$) EPC9511 Rev. 1.0

Symbol	Parameter	Conditions	Min	Max	Units
V_{IN}	Main Input Voltage Range – Pre-Regulator Mode	Also Used in Bypass Mode for Logic Supply	17	24	V
V_{IN}	Amplifier Input Voltage Range	Bypass Mode	0	80	V
V_{IN_UVLO+}	V_{IN} Rising Threshold	Regulated Mode Only		18.3	V
V_{IN_UVLO-}	V_{IN} Falling Threshold	Regulated Mode Only	17.3		V
V_{AMP}	Amplifier Supply Voltage	Regulated AirFuel Mode Regulated Qi/PMA Mode		66 26	V
I_{OUT}	Switch Node Output Current			1.7*	A
V_{extosc}	External Oscillator Input Threshold	Input 'Low' Input 'High'	-0.3 2.4	0.8 5	V
$V_{Pre\_Disable}$	Pre-regulator Disable Voltage Range	Floating	-0.3	5.5	V
$I_{Pre\_Disable}$	Pre-regulator Disable Current	Floating	-10	10	mA
V_{Ext_Osc}	External Oscillator Voltage Range	Open Drain/ Collector	-0.3	5	V
I_{Ext_Osc}	External Oscillator Current Range	Open Drain/ Collector	-25	25	mA
V_{Mode_Src}	Mode Select Source Voltage		4.5	5.5	V
I_{Mode_Src}	Mode Select Source Current			30	mA
V_{Mode_Sel}	Mode Select Input Voltage	AirFuel and Qi/PMA modes	-0.3	5.1	V
I_{Mode_Sel}	Mode Select Input Current	AirFuel and Qi/PMA modes	-50	30	mA
V_{Mode_Ret}	Mode Select Return Voltage		-2.5	2.5	V
I_{Mode_Ret}	Mode Select Return Current		-25	25	mA

* Maximum current depends on die temperature – actual maximum current will be subject to switching frequency, bus voltage and thermals.

Only one parameter at any time is used to control the pre-regulator with the highest priority being the maximum voltage supplied to the amplifier followed by the power delivered to the amplifier and lastly the magnitude of the coil current. The maximum amplifier supply voltage is pre-set to 66 V in AirFuel mode and 26 V in Qi/PMA mode and the maximum power drawn by the amplifier is pre-set to 10 W in either mode. The coil current magnitude is pre-set to 580 mA$_{RMS}$ in AirFuel mode and 1500 mA$_{RMS}$ in Qi/PMA mode, but can be made adjustable using P25. The pre-regulator comprises a SEPIC converter that can operate at full power with an input supply voltage from 17 V through 24 V.

The pre-regulator can be bypassed by connecting the positive supply directly to the ZVS class D amplifier supply after removing the jumper at location JP1 and connecting the main positive supply to the bottom pin. JP1 can also be removed and replaced with a DC ammeter to directly measure the current drawn by the amplifier. When doing this, the operator must provide a low impedance connection to ensure continued stable operation of the controller. Together with the Kelvin voltage probes (TP1 and TP2) connected to the amplifier supply, an accurate measurement of the power drawn by the amplifier can be made.

The EPC9511 is also provided with a miniature high efficiency switch-mode 5 V supply to power the logic circuits on board such as the gate drivers and oscillator allowing the EPC9511 board to operate from a single source.

The amplifier comes with two of its own low supply current oscillators. This first oscillator is pre-programmed to 6.78 MHz ± 678 Hz and the second to 165 kHz. The oscillator signal can be disconnected by removing jumper JP71 and can then be sourced from an external oscillator when connected to J70. J70 can also serve as an oscillator reference output when using the internal oscillators.

The pre-regulator can be disabled by inserting a jumper into JP50. However, note that this connection is floating with respect to the ground so removing the jumper for external connection requires a floating switch to correctly control this function. Refer to the datasheet of the controller IC and the schematic in this QSG for specific details.

The EPC9511 is provided with 3 LED's that indicate the mode of operation of the system. If the system is operating in coil current limit mode, then the green LED will illuminate. For power limit mode, the yellow LED will illuminate. Finally, when the pre-regulator reaches maximum output voltage the red LED will illuminate indicating that the system can no longer regulate either the coil current or delivered power. This can occur when the magnitude of the load impedance is too high in AirFuel mode or if the device unit draws insufficient current in the inductive (Qi) mode.

The EPC9511 amplifier is also equipped with Under Voltage Lockout (UVLO) protection which prevents the amplifier from starting up with insufficient voltage on the main supply. This feature is only operational in the regulated mode and does not affect operation in bypass mode. In addition, the EPC9511 has protection against reverse polarity connection of the main supply that is capable of conducting as much as 11 A$_{DC}$ for a short period.
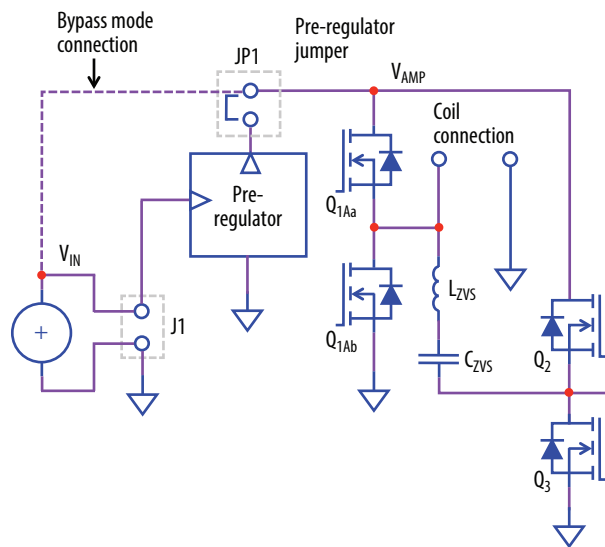

Figure 3: Power circuit schematic of EPC9511 amplifier.

ZVS Timing Adjustment (AirFuel Mode ONLY)

Setting the correct time to establish ZVS transitions is critical to achieving high efficiency with the EPC9511 amplifier when operating at high frequency. This can be done by selecting the values for R71 and R72 or P71 and P72 respectively. This procedure is best performed using a potentiometer installed at the appropriate locations (P71 and P72) that is used to determine the fixed resistor values. The timing MUST initially be set WITHOUT the source coil connected to the amplifier. The timing diagrams are given in figure 8 and should be referenced when following this procedure. Only perform these steps if changes have been made to the board as it is shipped preset. The steps are:

1. With power off, remove the jumper in JP1 and install it into JP50 to place the EPC9511 amplifier into Bypass mode. Connect the main input power supply (+) to JP1 (bottom pin – for bypass mode) with ground connected to J1 ground (-) connection.

2. With power off, connect the control input power supply bus (19 V) to Vin+ connector (J1). Note the polarity of the supply connector.

3. Connect a LOW capacitance oscilloscope probe to the probe-hole of the half-bridge to be set and lean against the ground post as shown in figure 7.

4. Turn on the control supply after ensuring that the supply is approximately 19 V with a 2 A current limit.

5. Turn on the main supply voltage to the required predominant operating value (such as 24 V but NEVER exceed the absolute maximum voltage of 80 V).

6. While observing the oscilloscope, adjust the applicable potentiometers to achieve the green waveform of figure 8.

7. Replace the potentiometers with fixed value resistors if required. Remove the jumper from JP50 and install it back into JP1 to revert the EPC9511 back to pre-regulator mode.

Determining component values for L_{ZVS} (AirFuel Mode ONLY)

The ZVS tank circuit is not operated at resonance, and only provides the necessary negative device current for self-commutation of the output voltage at turn off. The capacitor C_{ZVS1} is chosen to have a very small ripple voltage component and is typically around 1 µF. The amplifier supply voltage and switch-node transition time will determine the value of inductance for $L_{ZVS} = L_{ZVS1} + L_{ZVS2}$ which needs to be sufficient to maintain ZVS operation over the DC device load resistance range and coupling between the device and source coil range. The value of the inductance can be calculated using the following equation:

$$L_{ZVS} = \frac{\Delta t_{vt}}{8 \cdot f_{sw} \cdot (C_{OSSQ} + C_{well})} \qquad (1)$$

Where:

Δt_{vt} = Voltage transition time [s]

f_{SW} = Operating frequency [Hz]

C_{OSSQ} = Charge equivalent device output capacitance [F].

C_{well} = Gate driver well capacitance [F]. Use 20 pF for the LM5113

NOTE. the amplifier supply voltage V_{AMP} is absent from the equation as it is accounted for by the voltage transition time. The C_{OSS} of the EPC2107 eGaN FETs is very low and lower than the gate driver well capacitance C_{well} which as a result must be now be included in the ZVS timing calculation. The charge equivalent capacitance can be determined using the following equation:

$$C_{OSSQ} = \frac{1}{V_{AMP}} \cdot \int_0^{V_{AMP}} C_{OSS}(v) \cdot dv \qquad (2)$$

To add additional immunity margin for shifts in coil impedance, the value of L_{ZVS} can be decreased to increase the current at turn off of the devices (which will increase device losses). Typical voltage transition times range from 2 ns through 12 ns.

QUICK START PROCEDURE

The EPC9511 amplifier board is easy to set up and evaluate the performance of the eGaN FET in a wireless power transfer application. Refer to figure 1 to assemble the system and figures 5 through 11 for proper connection and measurement setup before following the testing procedures.

The EPC9511 can be operated using any one of two alternative methods to either wireless power standard:

a. Using the pre-regulator.

b. Bypassing the pre-regulator.

a. Operation using the pre-regulator

The pre-regulator is used to supply power to the amplifier in this mode and will limit the coil current, power delivered or maximum supply voltage to the amplifier based on the pre-determined settings.

The main 19 V supply must be capable of delivering 2 A_{DC}. It is not necessary to turn up the voltage of this supply when instructed to power up the board, instead simply turn on the supply.

1. Make sure the entire system is fully assembled prior to making electrical connections and make sure jumper JP1 and JP71 are installed. Select AirFuel or Qi/PMA mode according to figure 5 and 6. Also make sure the source coil is attached to the amplifier and that the device board is connected to a load.

2. With power off, connect the main input power supply bus to J1 as shown in figure 4. Note the polarity of the supply connector.

3. Make sure all instrumentation is connected to the system.

4. Turn on the main supply voltage (19 V). It is not necessary start at 0 V. Instead, preset the voltage to 19 V and then power up.

5. Once operation has been confirmed, observe the output voltage, efficiency and other parameters on both the amplifier and device boards.

6. For shutdown, please follow the above five steps in the reverse order.

b. Operation bypassing the pre-regulator

In this mode, the pre-regulator is bypassed and the main power is connected directly to the amplifier. This allows the amplifier to be operated using an external regulator. NOTE: In this mode there is no protection for ensuring the correct operating conditions for the eGaN devices.

1. Make sure the entire system is fully assembled prior to making electrical connections and make sure jumper JP1 has been removed and installed in JP50 to disable the pre-regulator and place the EPC9511 in bypass mode. Also make sure a source coil is attached to the amplifier and that device board is connected to a load.

2. With power off, connect the main input power supply bus to the bottom pin of JP1 and the ground to the ground connection of J1 as shown in figure 4.

3. With power off, connect the control input power supply bus to $+V_{IN}$ (J1). Note the polarity of the supply connector. This is used to power the gate drivers and logic circuits.

4. Make sure all instrumentation is connected to the system.

5. Turn on the control supply – make sure the supply is in the 19 V range.

6. Turn on the main supply voltage to the required value (it is recommended to start at 0 V and do not exceed the absolute maximum voltage of 80 V or the current rating of the main EPC2107 ICs).

7. Once operation has been confirmed, adjust the main supply voltage within the operating range and observe the output voltage, efficiency and other parameters on both the amplifier and device boards. Monitor the temperature of the FETs as device failures can occur if the junction temperature exceeds 150°C.

8. For shutdown, please follow the above steps in the reverse order. Start by reducing the main supply voltage to 0 V followed by steps 6 through 2.

NOTE.
1. When measuring the high frequency content switch-node (Source Coil Voltage), care must be taken to avoid long ground leads. An oscilloscope probe connection (preferred method) has been built into the board to simplify the measurement of the Source Coil Voltage (shown in Figure 7).

2. AVOID using a Lab Benchtop programmable DC load as the load for the device boards. These loads have low control bandwidth and will cause the EPC9511 system to oscillate at a low frequency and may lead to failure. It is recommended to use a fixed low inductance resistor as an initial load. Once a design matures, a post regulator, such as a Buck converter, can be used.

THERMAL CONSIDERATIONS

The EPC9511 demonstration system showcases the EPC2107, EPC2036, and EPC2038 eGaN FETs and ICs in a wireless energy transfer application. Although the electrical performance surpasses that of traditional silicon devices, their relatively smaller size does magnify the thermal management requirements. The operator must observe the temperature of the gate driver and eGaN FETs to ensure that both are operating within the thermal limits as per the datasheets.

NOTE. The EPC9511 demonstration system has limited current protection only when operating off the pre-regulator. When bypassing the pre-regulator there is no current protection on board and care must be exercised not to over-current or over-temperature the devices. Excessively wide coil coupling and load range variations can lead to increased losses in the devices.

Precautions

The EPC9511 demonstration system has no controller or enhanced protection systems and therefore should be operated with caution. Some specific precautions are:

1. Never operate the EPC9511 system with a receiving device board that is AirFuel, Qi or PMA compliant as this system does not communicate with the device to correctly setup the required operating conditions. Doing so can lead to failure of the compliant device unit. Contact EPC to obtain instructions should operating the system with a compliant device be required. Please contact EPC at info@epc-co.com should the tuning of the coils be required to be changed to suit specific conditions so that it can be correctly adjusted for use with the ZVS class-D amplifier.

2. There is no heat-sink on the devices and during experimental evaluation it is possible to present conditions to the amplifier that may cause the devices to overheat. Always check operating conditions and monitor the temperature of the EPC devices using an IR camera.

3. Never connect the EPC9511 amplifier board into your VNA in an attempt to measure the output impedance of the amplifier. Doing so will severely damage the VNA. Contact EPC should you require information on the output impedance of the amplifier.

4. It is strongly recommended to place a 5 mm thick Plexiglas spacer on top of the source coil during testing to protect the user from exposed electrical contacts and static discharge that can cause the amplifier to fail.

5. The operator should not change oscilloscope probe locations or measurements on the board while in operation. Turn off first before moving the probe to a new location. Failure to follow this recommendation can lead to board failure.

6. Never touch the coil, or any exposed conductors on the any of the coils to avoid RF burns and potential failure of the amplifier.

NOTE.
The EPC9511 can also be purchased as part of EPC9121 demonstration kit. The EPC9121 wireless power system comprises four boards namely:

1. A multi-mode capable EPC9511 source board (transmitter or power amplifier)

2. A multi-mode source coil (transmit coil) compatible with the AirFuel Class 2 standard and Qi (A6) /PMA standards

3. An AirFuel compatible Category 3 AirFuel device coil (receive coil) with rectifier and DC output

4. A Wireless Power Consortium (Qi) and Power Matters Alliance (now AirFuel) compatible device coil (receive coil) with rectifier and DC output
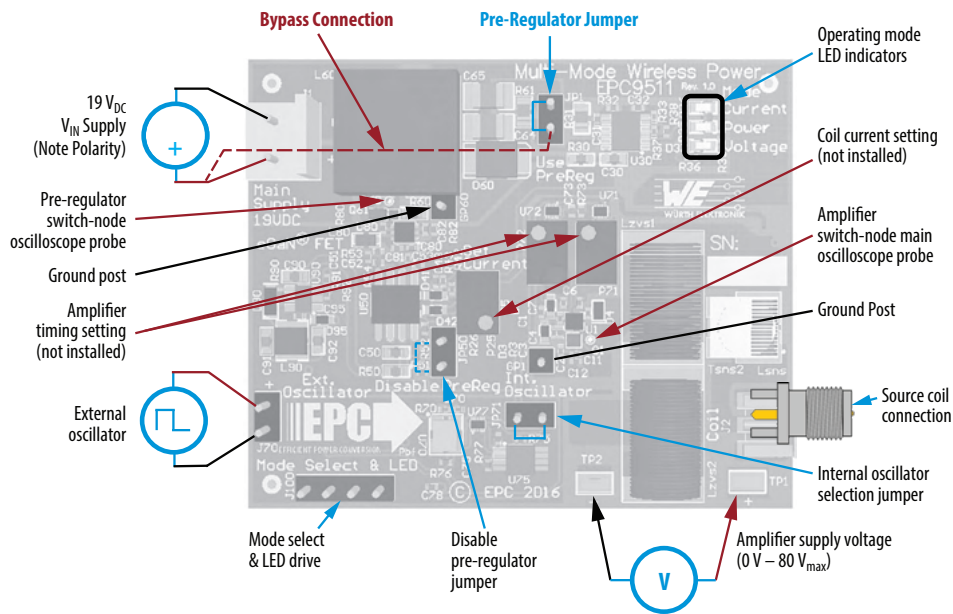
Figure 4: Proper connection and measurement setup for the EPC9511 amplifier board.

- Circuit not included with demo
- Shown in AirFuel mode position
- **Switch MUST have OFF position!**
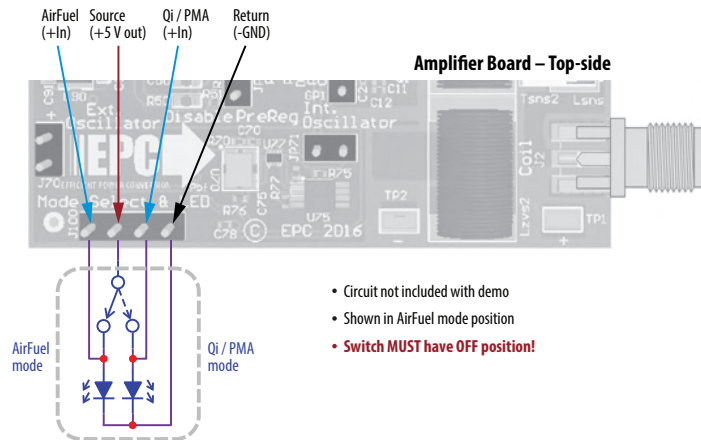
Figure 5: Proper connection setup for operating mode selection using a switch and LEDs.

Mode select jumper position:
Solid = AirFuel mode
Dash = Qi/PMA mode
GND = Not used

Figure 6: Proper connection setup for operating mode selection using jumpers.

Figure 7: Proper measurement of switch Node waveforms.

Figure 8: ZVS timing diagrams

Table 2: Bill of Materials - Amplifier Board

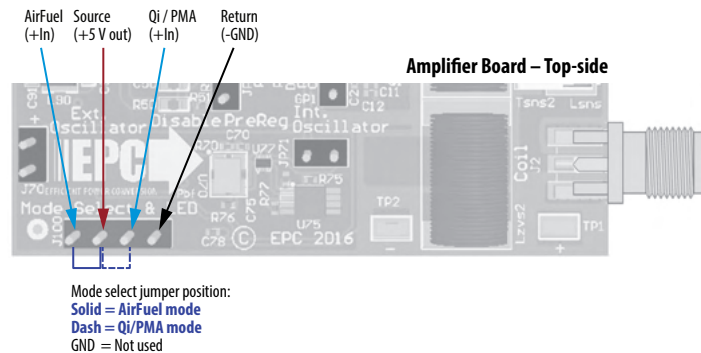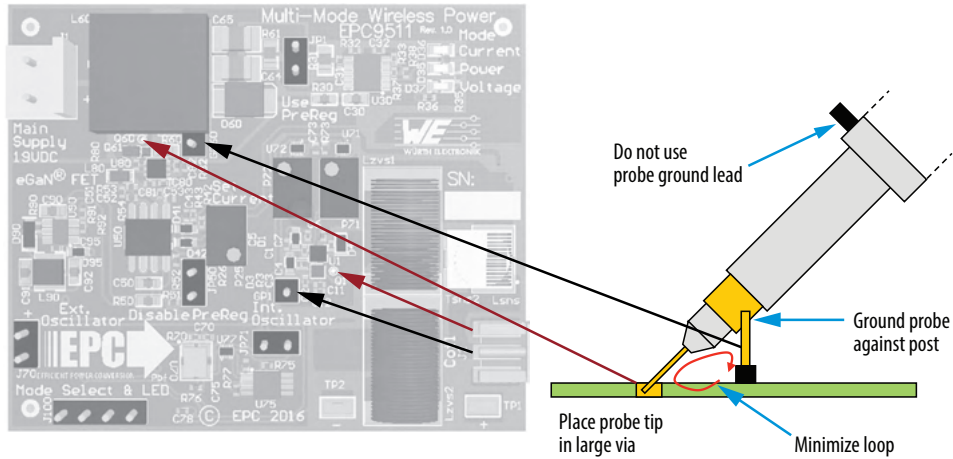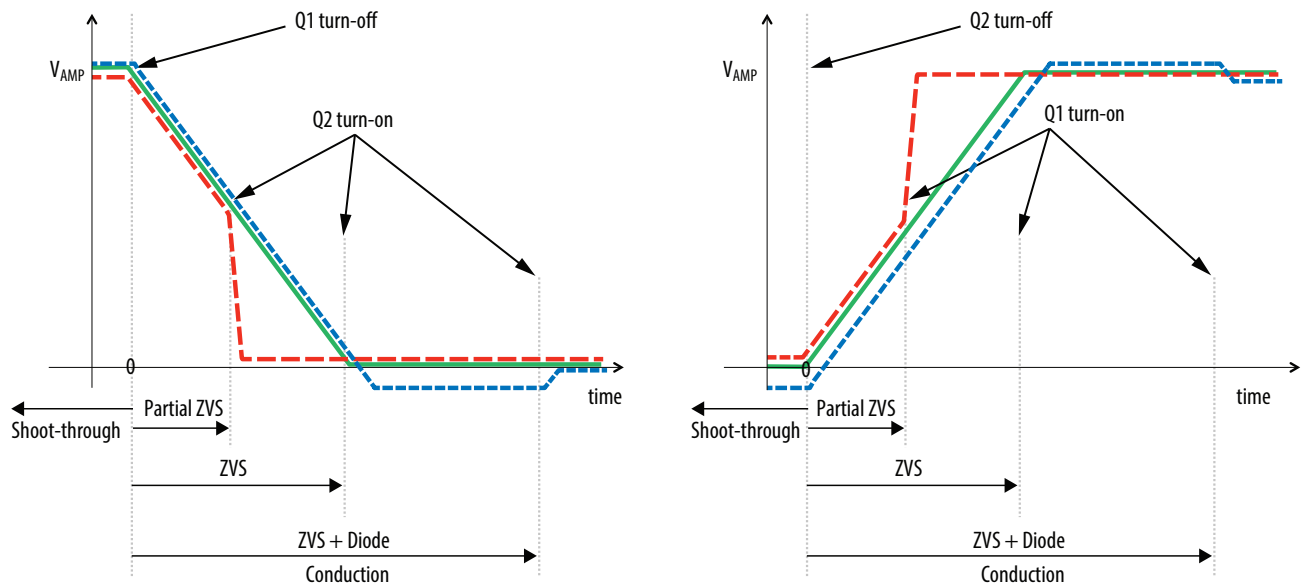| Item	Qty	Reference	Part Description	Manufacturer	Part #
1	2	C1, C80	1 µF, 10 V	Würth	885012105012
2	2	C11, C12	10 nF, 100 V	TDK	C1005X7S2A103K050BB
3	3	C15, C64, C65	2.2 µF 100 V	Taiyo Yuden	HMK325B7225KN-T
4	16	C2, C4, C5, C51, C70, C71, C72, C75, C77, C78, C81, C100, C101, C130, C200, C210	100 nF, 25 V	Würth	885012105018
5	5	C20, C22, C46, C131, C135	1 nF, 50 V	Würth	885012205061
6	1	C21 (Only Populate with Tsns1)	680 pF, 50 V	Murata	GRM155R71H681KA01D
7	1	C45 (Not Populated)	10 nF, 100 V	Murata	C1005X7S2A103K050BB
8	1	C73 (Not Populated)	22 pF, 50 V	TDK	C1005C0G1H220J050BA
9	2	C133, C223 (Not Populated)	1 nF, 50 V	Murata	GRM1555C1H102JA01D
10	1	C220	100 nF, 16 V	Würth	885012205037
11	1	C221	1 nF, 50 V	Murata	GRM1555C1H102JA01D
12	1	C27	82 nF, 16 V	Murata	GRM155R71C823KA88D
13	2	C3, C95	22 nF, 25 V	Würth	885012205052
14	2	C30, C50	100 nF, 100 V	Murata	GRM188R72A104KA35D
15	1	C32	47 nF, 25 V	Würth	885012205054
16	2	C43, C53	10 nF, 50 V	Würth	885012205067
17	1	C52	100 pF, 50 V	Würth	885012005061
18	5	C6, C7, C31, C44, C82	22 pF, 50 V	Würth	885012005057
19	2	C61, C62	4.7 µF, 50 V	Würth	885012209048
20	1	C63	10 µF, 35 V	Taiyo Yuden	GMK325BJ106KN-T
21	3	C90, C91, C92	1 µF, 25 V	Murata	GRM188R61E105KA12D
22	1	Czvs1	1 µF, 50 V	Würth	885012207103
23	2	D1, D95	40 V, 300 mA	ST	BAT54KFILM
24	11	D2, D3, D21, D40, D41, D42, D47, D48, D49, D71, D72	40 V, 30 mA	Diodes Inc.	SDM03U40-7
25	1	D20	25 V, 11 A	Littelfuse	SMAJ22A
26	2	D203, D221	3 V9, 150mW	Bournes	CD0603-Z3V9
27	1	D35	LED 0603 Yellow	Würth	150060YS75000
28	1	D36	LED 0603 Green	Würth	150060VS75000
29	1	D37	LED 0603 Red	Würth	150060RS75000
30	3	D4, D100, D101	5 V1, 150 mW	Bournes	CD0603-Z5V1
31	1	D60	100 V, 1A	On-Semi	MBRS1100T3G
32	1	D90	40 V, 1A	Diodes Inc.	PD3S140-7
33	2	GP1, GP60	.1" Male Vert.	Würth	61300111121
34	1	J1	.156" Male Vert.	Würth	645002114822
35	1	J100	.1" Male Vert.	Würth	61300411121
36	1	J2	SMA Board Edge	Linx	CONSMA003.062
37	4	J70, JP1, JP50, JP71	.1" Male Vert.	Würth	61300211121
38	3	JP10, JP72, JP100	.1" Shunt Jumper	Würth	60900213421
39	1	L60	100 µH 2.2 A	Würth	744871101
40	1	L80	10 µH 150 mA	Würth	74479778310
41	1	L90	47 µH 250 mA	Würth	7440329470
42	1	Lsns (Only Populate with Tsns1)	82 nH (only with Tsns1)	CoilCraft	1515SQ-82NJEB
43	2	Lzvs1, Lzvs2	390 nH	CoilCraft	2929SQ-391JE
44	1	P25	10 kΩ	Murata	PV37Y103C01B00
45	2	P71, P72	1 kΩ	Murata	PV37Y102C01B00
46	3	Q1	100 V 220 mΩ with Sync Boot FET	EPC	EPC2107
47	3	Q2, Q3, Q60	100 V 65 mΩ	EPC	EPC2036
48	1	Q20, Q46, Q135	100 V 2.8 Ω	EPC	EPC2038
49	3	Q61 (Not Populated)	100 V 6 A 30 mΩ	EPC	EPC2007C
50	1	R132, R200, R222	18 kΩ 1%	Panasonic	ERJ-2RKF1802X
51	1	R133	6.81 kΩ 1%	Panasonic	ERJ-2RKF6811X
52	2	R134	470 kΩ	Panasonic	ERJ-2RKF4703X
53	1	R2, R82	20 Ω	Panasonic	ERJ-2RKF20R0X
54	1	R201	4.53 kΩ 1%	Panasonic	ERJ-2RKF4531X
55	1	R21	51 Ω 1/2 W (with Tsns2), 10 kΩ (with Tsns1)	Panasonic	ERJ-P06J510V / ERJ-P06J103V
56	1	R220	71.5 kΩ	Panasonic	ERJ-3EKF7152V
57	1	R223	6.8 kΩ 1%	Panasonic	ERJ-2RKF6801X

Table 2: Bill of Materials - Amplifier Board (continued)

Item	Qty	Reference	Part Description	Manufacturer	Part #
58	1	R224	330 kΩ	Panasonic	ERJ-2RKF3303X
59	1	R25	4.3kΩ 1% (with Tsns2), 6.81 kΩ (with Tsns1)	Panasonic	ERJ-2RKF4301X / ERJ-2RKF6811X
60	1	R26	22 kΩ 1% (with Tsns2), 2.8 kΩ (with Tsns1)	Panasonic	ERJ-2RKF2202X / ERJ-2RKF2801X
61	1	R27	3.3 kΩ 1%	Panasonic	ERJ-2RKF3301X
62	4	R3	27 kΩ	Panasonic	ERJ-2RKF2702X
63	1	R30, R102, R103, R104	100 Ω	Panasonic	ERJ-3EKF1000V
64	1	R31	71 kΩ 5 1%	Panasonic	ERJ-6ENF7152V
65	1	R32	8.2 kΩ 1%	Panasonic	ERJ-2RKF8201X
66	2	R33	75 kΩ	Panasonic	ERJ-2RKF7502X
67	1	R35, R36	634 Ω	Panasonic	ERJ-2RKF6340X
68	2	R37	150 kΩ 1%	Panasonic	ERJ-2RKF1503X
69	1	R38, R91	49.9 kΩ 1%	Panasonic	ERJ-2RKF4992X
70	4	R4	4.7 Ω	Stackpole	RMCF0402FT4R70
71	4	R40, R130, R202, R203	261 kΩ	Panasonic	ERJ-3EKF2613V
72	1	R41, R49, R131, R221	6.04 kΩ	Panasonic	ERJ-2RKF6041X
73	2	R42	36.5 kΩ	Panasonic	ERJ-2RKF3652X
74	1	R43, R48	15.4 kΩ	Panasonic	ERJ-2RKF1542X
75	1	R45 (Not Populated)	1.5 kΩ	Panasonic	ERJ-2RKF1501X
76	2	R44, R90	100 kΩ 1%	Panasonic	ERJ-2RKF1003X
77	2	R46, R135	11.3 kΩ	Panasonic	ERJ-2RKF1132X
78	1	R50	10 Ω	Panasonic	ERJ-3EKF10R0V
79	1	R51	124 kΩ 1%	Panasonic	ERJ-2RKF1243X
80	1	R52	71.5 kΩ 1%	Panasonic	ERJ-2RKF7152X
81	1	R53	1.00 kΩ	Panasonic	ERJ-2RKF1001X
82	1	R54	0 Ω	Panasonic	ERJ-2GE0R00X
83	1	R60	80 mΩ 0.4 W	Vishay Dale	WSLP0603R0800FEB
84	1	R61	220 mΩ 0.333 W	Susumu	RL1220S-R22-F
85	1	R70	47 kΩ	Panasonic	ERJ-2RKF4702X
86	1	R71	430 Ω	Panasonic	ERJ-2RKF4300X
87	1	R72	180 Ω	Panasonic	ERJ-2RKF1800X
88	5	R73, R76, R77, R100, R101	10 kΩ	Panasonic	ERJ-2RKF1002X
89	1	R75	68 kΩ	Panasonic	ERJ-2RKF6802X
90	1	R80	2.2 Ω	Stackpole	RMCF0402FT2R20
91	1	R92	9.53 kΩ 1%	Panasonic	ERJ-2RKF9531X
92	2	TP1, TP2	SMD Probe Loop	Keystone	5015
93	1	Tsns1 (Not Populated)	10 µH 1:1 96.9%	CoilCraft	PFD3215-103ME
94	1	Tsns2	1:20 Current Xrmr	CoilCraft	CST7030-020LB
95	1	U1	100 V eGaN Driver	National Semiconductor	LM5113TM
96	3	U130, U200, U220	Comparator	Texas Instruments	TLV3201AIDBVR
97	1	U210	+Edge-trig D-Flop with Clr & Rst	Fairchild	NC7SZ74L8X
98	1	U30	Power & Current Monitor	Linear	LT2940IMS#PBF
99	1	U50	Boost Controller	Texas Instruments	LM3478 mAX/NOPB
100	1	U70	Pgm Osc.	EPSON	SG-8002CE-PHB-6.780MHz
101	1	U71	2 In NAND	Fairchild	NC7SZ00L6X
102	1	U72	2 In AND	Fairchild	NC7SZ08L6X
103	1	U75	Dither Oscillator	mAxim	DS1090U-32+
104	1	U77	MUX	Fairchild	NC7SZ157L6X
105	1	U78	Reconfig Logic 57	Fairchild	NC7SZ57L6X
106	1	U80	Gate Driver with LDO	Texas Instruments	UCC27611DRV
107	1	U90	1.4 MHz 24 V 0.5 A Buck	MPS	MP2357DJ-LF
108	1	PCB	EPC9511 Amplifier Board	EPC	B5008 Rev. 1.0

EPC would like to acknowledge Würth Electronics (www.we-online.com/web/en/wuerth_elektronik/start.php) for their support of this project.

Table 3: Off Board Components

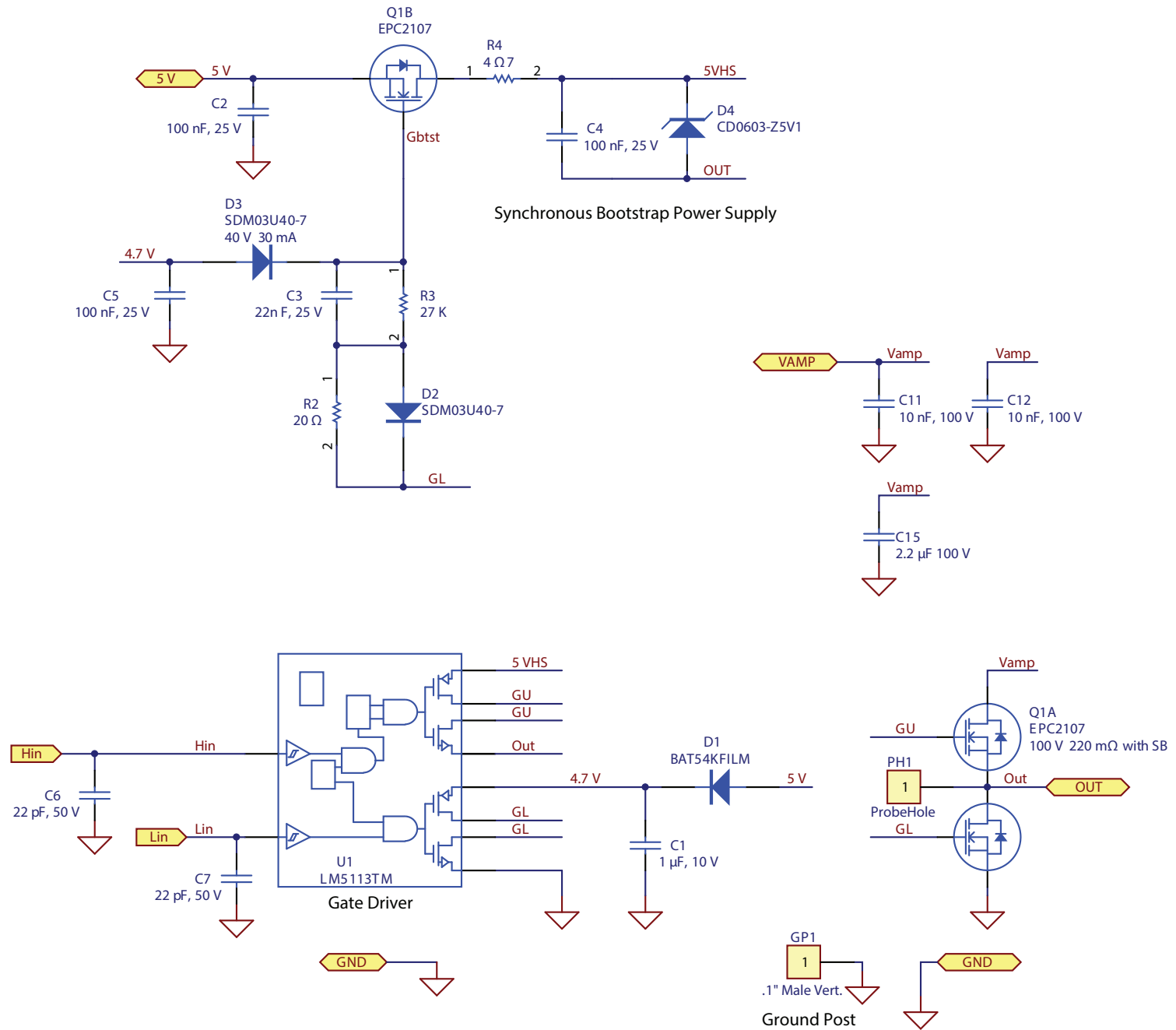| Item	Qty	Reference	Part Description	Manufacturer	Part #
1	1	SW1000	Rocker SW SPDT 120 V 5 A	E-Switch	100SP3T1B1M1QEH
2	2	D1000, D1001	40x12mm LED backlight	BCrobotics	LEDB-003
3	1	J1000	Con4x1.1F	TE Connectivity	534237-2
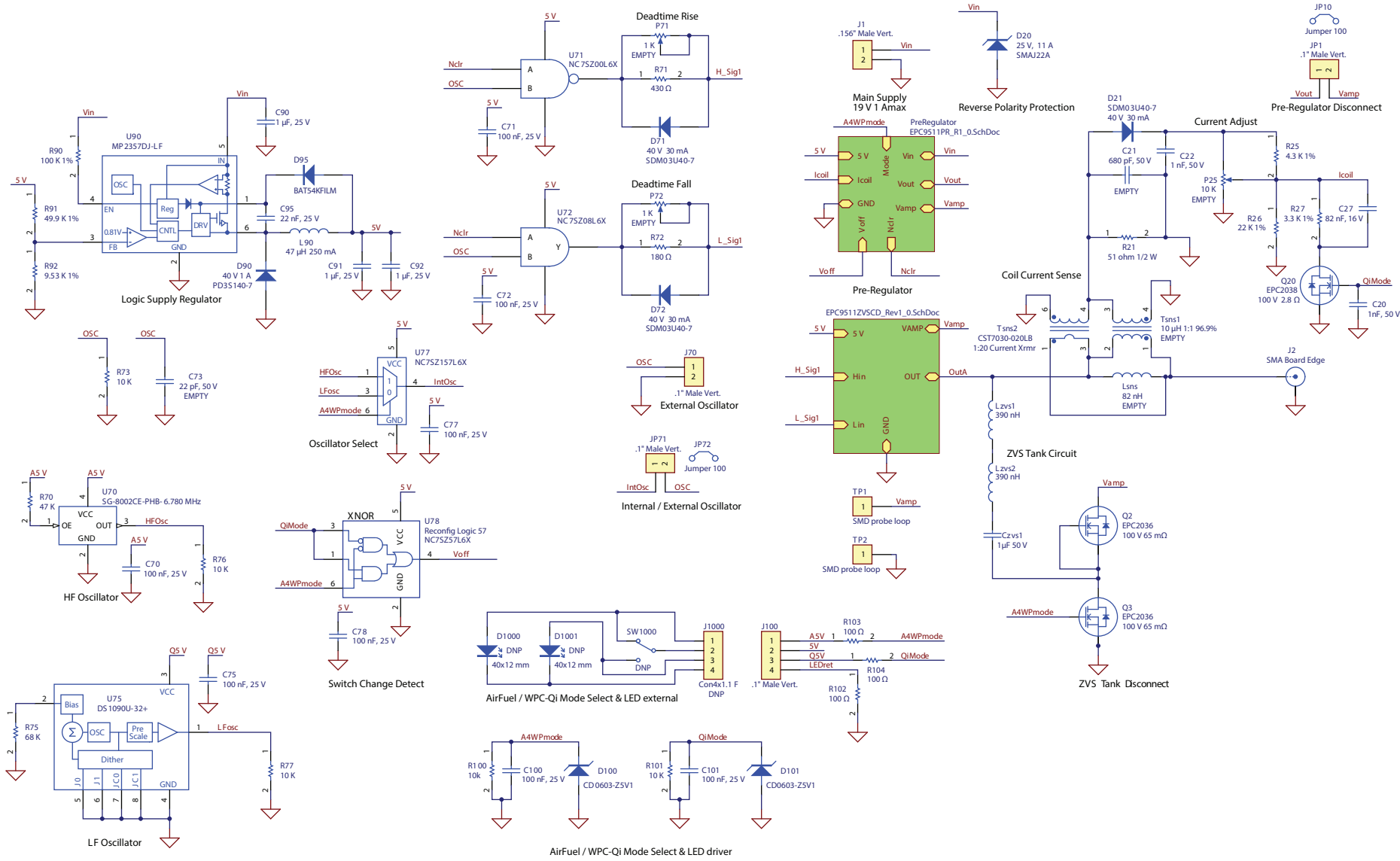
Figure 9: EPC9511 - ZVS class-D amplifier schematic

Development Board EPC9511

Q1B
EPC2107

R4
4 Ω 7

5 V

5 V

C2
100 nF, 25 V

Gbtst

C4
100 nF, 25 V

5VHS

D4
CD0603-Z5V1

OUT

Synchronous Bootstrap Power Supply

D3
SDM03U40-7
40 V 30 mA

4.7 V

C5
100 nF, 25 V

C3
22n F, 25 V

R3
27 K

R2
20 Ω

D2
SDM03U40-7

GL

VAMP

Vamp

Vamp

C11
10 nF, 100 V

C12
10 nF, 100 V

Vamp

C15
2.2 µF 100 V

5 VHS

GU
GU

Out

Hin

Hin

C6
22 pF, 50 V

Lin

Lin

C7
22 pF, 50 V

U1
LM5113TM

Gate Driver

GL
GL

D1
BAT54KFILM

4.7 V

5 V

C1
1 µF, 10 V

GND

GU

PH1

1

ProbeHole

Q1A
EPC2107
100 V 220 mΩ with SB

Out

OUT

GL

Vamp

GP1

1

.1" Male Vert.

Ground Post

GND

Figure 10: EPC9511 - Gate driver and power devices schematic

Mode Switch protection

Output Voltage Limit

Output Power Limit

Output Current Limit

PreRegulator Disable

Gate Driver

DC Power Monitor

Power Mode

Current Mode

Voltage Mode

Ground Post

Voltage Switch Threshold Detect

Voltage Switch Threshold Latch

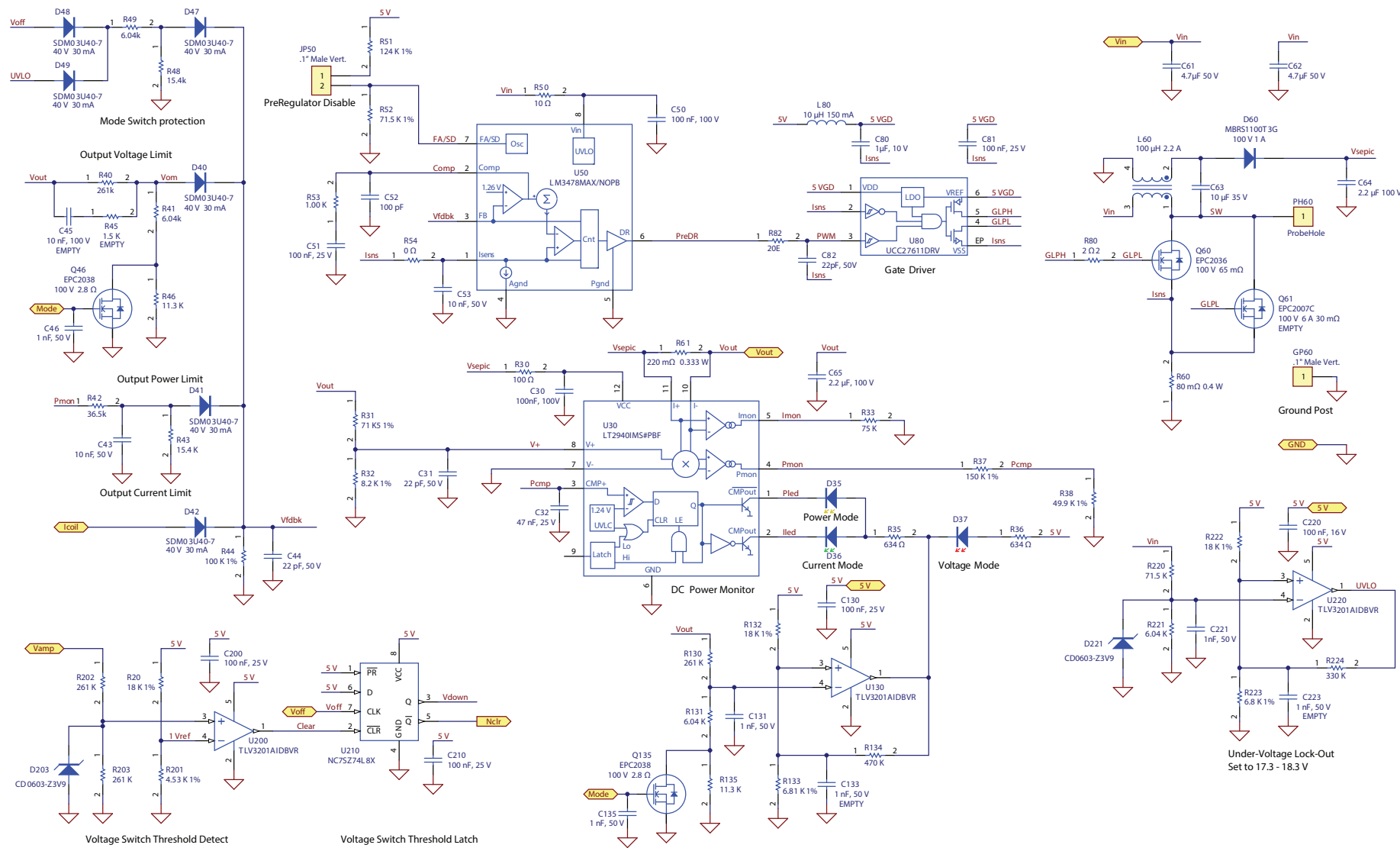Under-Voltage Lock-Out
Set to 17.3 - 18.3 V

Figure 11: EPC9511 - Pre-regulator schematic

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